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Current EV Charger State-of-the-Art

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Abstract
According to recent utility provider reports, there are situations in which the integration of renewable energy sources could lead to harmful Transient Over-Voltages (TOV) in the electrical grid. With more electric vehicle (EV) charging stations available, stations in residential areas, EV batteries' ability to reduce TOVs is being investigated. This study examines the most recent advancements in EV charger technology in terms of the charging methods that are being used and how well they can reduce over voltages. Additionally, charging system power ratings are examined, along with communication plans and maximum power influx control. System response times and corresponding time limitations are also established.

Keywords: electric vehicle, wireless charging, wireless power transfer, inductive power transfer, capacitive power transfer. dynamic wireless charging

I. INTRODUCTION

With total sales of over 286,000 vehicles as of July 2014, the United States possessed the world's largest fleet of highway-capable plug-in electric cars (see the Electric Vehicle Transportation Center (EVTC) In 2010, 0.19% of the 117,538,000 homes in the US had an electric vehicle of some kind. By 2019, almost 1% of US households will possess an electric vehicle if EV sales growth continues. The literature has covered this development's potential benefits and drawbacks for vehicle-to-grid (V2G) integration in great detail [1, 2, 3, 4, 5]. Furthermore, research on grid-integrated EVs' capacity to level out peak load is still underway [6,7,8,9]. EV batteries have been suggested as a potential buffer for renewable energy sources such However, recent utility provider reports have demonstrated that the integration of renewable energy sources may occasionally result in harmful transient over-voltages in the grid [10]. Temporary, abrupt voltage spikes (TOVs) occur along the grid's electric lines. In the event that there is insufficient mitigation, TOVs may harm the adjunct homes' personal electric devices or utility equipment. TOVs, for instance, may happen when a distribution circuit's generated power surpasses its load when the circuit is disconnected. Isolations may result from the utility company's routine operating processes, such as switching to a backup circuit, or from the failure of safety devices, such as fuses. In the context of photovoltaic (PV) power, a number of PV inverter control solutions have been put out to stop TOVs in distribution networks. Reno and colleagues recommended modifying the power factor based on past experiences of when high During the day, voltages from the load or the solar output usually occur [11]. Other Volt/Var control's capabilities and implementation have been examined by writers [12,13, 14]. Moreover, a number of reactive power optimal control schemes have been researched [15,16,17, 18]. The drawback of inverter-based TOV control methods is the requirement for a separate control module to be installed in each inverter. It would be necessary to replace or update the current inverters. Furthermore, if a single inverter is utilized, TOVs can both cause them and cannot be prevented. Utility companies have recently released data indicating that the integration of renewable energy sources may result in harmful TOVs in the system under certain conditions. Therefore, it is reasonable to assume that EVs linked to the grid through residential or commercial charging In the foreseeable future, stations may become commonplace in many communities. If TOVs cannot be avoided altogether, grid-connected EV batteries may be able to absorb them in addition to peak load balancing. Converter-based charging stations are frequently utilized as the intermediary between EV batteries and the utility grid. They may be able to address the utility issues associated with TOVs for a more secure and effective integration of residential PVs into the grid if they are specifically made for the purpose.

The development of EV charging technology is still in its infancy. Numerous technologies are available and are employed in accordance with different characteristics, regional customs, and laws: • Type, rating, and capacity of EV batteries • International charging standards (such as the IEC 61851-1:2010 conductive charging standard, the Japanese-developed CHAdeMO standard, or the Society of Automotive Engineers (SAE) International J1772 Combo standard). • Typical EV usage patterns, such as short versus lengthy travels, one daily versus numerous, slow overnight charge versus fast charging, etc. • grid characteristics, such as maximum grid current, voltage, and phase. • Financial limitations This paper examines the state-of-the-art EV charger technology in relation to the following in order to find potentials of EV batteries for TOV reduction: • used charging technologies and their capabilities to reduce over-voltages • maximum power input; the power rating of charging systems; control and

II. Technology of Battery Chargers

PV power generation is given as an example to help explain the electrical needs for the grid and battery charging. When using PV in a home, electrical sub In the US, circuits usually have a power of 0.5–20 kW. Therefore, in accordance with [10], any suggested remedy for TOV mitigation must satisfy the following conditions: 2. The TOV mitigation should start when the voltage is 120% above the normal voltage (144V in the US), and it should be effective for at least one cycle, or 1/60th of a second.

Therefore, all system elements of the grid-to-battery charging infrastructure should be able to carry out the aforementioned duties in compliance with safety standards. This covers protocols, communication devices, sensors, and controllers. The sections that follow take a EV charger technology is analyzed using a top-down method that begins at the system level and ends with individual parts and controllers.

2.1 EV charging station classification

Methods for classifying charging stations according to their power were introduced by the International Electro technical Commission (IEC) and the Society of Automotive Engineers (SAE). level and the appropriate charging modes for them.

2.2. SAE's power level-based EV charging classification system

The Society of Automotive Engineers maintains a standard for electrical connectors for electric vehicles called "SAE Surface Vehicle Recommended Practice J1772, SAE Electric Vehicle Conductive Charge Coupler" (short: SAE J1772) [19]. It includes all of the technical details of conductive charge technology, including electrical requirements, communication protocols, and performance standards. Three distinct power levels are used by SAE J1772 to differentiate between charging stations. There is a lot of flexibility for component combinations and operating choices within these levels to support various

Table 2.1: Categorization of charging levels according to SAE J1772 (2009)

	Level 1 Charging	Level 2 Charging	DC Fast Charge (Level 3)
Voltage	Single Phase AC, 120V	Single or Three Phase AC, 240V	Direct Current DC, 200-600V
Peak Current	16A	80A (since 2009)	400A
Maximum Power	1.92kW	19.2kW	240kW
Charging Station	grounded receptacles for domestic application, domestic socket outlet, or Level 1 charging station	Level 2 charging station, cable permanently fixed to charging station	Level 3 charging station
Coupler/Connector	domestic power cord, SAE J1772	IEC 62196-2 Type 2,IEC 62196-2 Type 3, etc.	SAE J1772 Hybrid Coupler, CHAdeMO, etc.
Charge times	6h (PHEV) to 24h (BEV)	2h (PHEV) to 8h (BEV)	10min (PHEV) to 30min (BEV)

First-Level Charging

A typical residential 120V AC outlet with a ground fault interrupter (GFI) and circuit breaker is used for level 1 charging [20]. Typically, installation expenses range from a few thousand to several hundred US dollars. The charger performs battery management, AC/DC conversion, DC/DC boost conversion, Power Factor Correction (PFC), and a number of filtering tasks [21]. The best uses are with low-range electric vehicles. With a specialized power cord that has an SAE J1772 connector on the vehicle side and a conventional domestic socket on the charging side, mid-range EVs and PHEVs can also be charged with Level 1 chargers. A schematic layout of a standard arrangement for a Level 1 EV charger is shown in Figure 2.1 [21]. The maximum for a home outlet with 16A and 120V

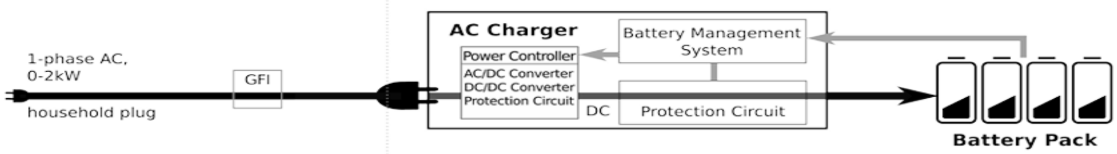


Figure 2.1: Level 1 EV charging setup

Charging at Level Two

For Level 2 charging, a specialized single- or three-phase 208-240V AC circuit is typically utilized. The charging station is secured with a GFI and circuit breaker. Once more, PFC, The charger performs a number of filtering tasks, battery management, DC/DC boost conversion, and AC/DC conversion. Through the coupling, a communication interface and safety interlock are formed between the on-board EV charger and the charging station. Since 2009, the highest delivered power has been up to 20kW with a peak current of 80A. The charging station has the charging cables permanently attached to it. The configuration of a Level 2 EV charging station is shown in Figure 2.2. Generally speaking, charging takes two to eight hours, depending on the battery's power needs. Consequently, Level 2

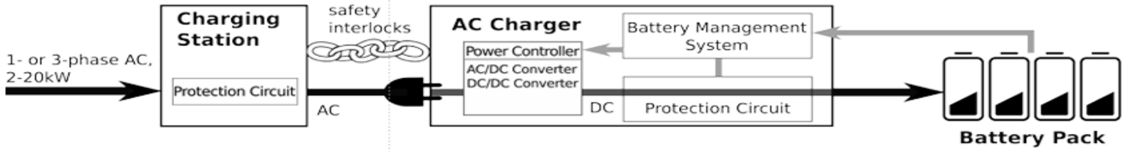


Figure 2.2: Level 2 EV charging setup

Level 3 Power Supply

Direct current DC charging, or Level 3 chargers, have a maximum power delivery capacity of 240kW. Up to 400A of very high current can be used to accomplish this. and 600V DC on a specific circuit connected to the grid at high amps. The charging station uses PFC, AC/DC conversion, and DC/DC boost conversion to supply variable DC straight to the EV charger. It is safeguarded by a number of safety measures. The Battery Management System (BMS) of the on-board charger connects to the charging station through CAN bus communication. The charging station and the charging wire are fixed. There are now several rival coupler standards in use, such as the CHAdeMO in Japan and the SAE J1772 Hybrid coupler in the US.A potential configuration for a DC charging station is shown in Figure 2.3. The normal charging duration is between 10 and 30 minutes. DC rapid charging stations can operate commercially, much like petrol stations, thanks to the relatively quick charging times. Profitable places could consist of commercial centers, traditional gas stations, and rest areas.

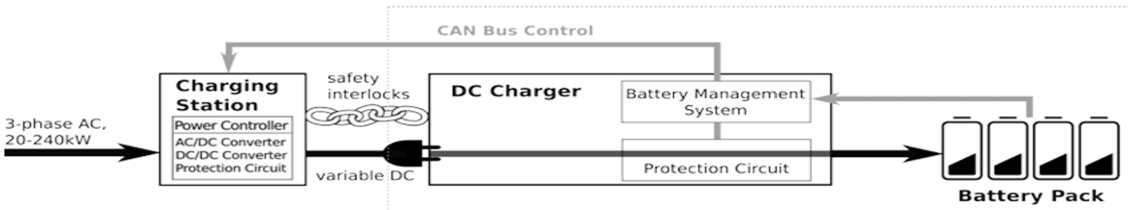


Figure 2.3: Level 3 EV charging setup

2.3 The IEC has classified EV charging based on charging modes.

The safety communication protocol between the EV and the charging station is described by the charging mode. A standard for plugs, socket outlets, connectors, and inlets is IEC 62196. and electric car cable assemblies designed to be used in conductive charging systems with control mechanisms. It makes reference to IEC 61851-1, "Vehicle Conductive Charging System - Part 1: General requirements," which defines the charging mode as the key to distinguishing between EV and conventional charging. Moreover, the IEC 61851-1 standard enhances IEC 62196 by specifying pilot signals that use pulse width modulation (PWM) to identify the charging requirements.

Table 2.2 gives an overview of the four charging modes.

	Mode 1	Mode2	Mode 3	Mode 4
Description	slow charging from a household-type socket-outlet	slow charging from a household-type socket-outlet with an in-cable protection device	slow or fast charging using a specific EV socket-outlet with control and protection function installed	fast charging using an external charger
Voltage	Single Phase AC < 250V or Three Phase AC < 480V	Single Phase AC < 250V or Three Phase AC < 480V	Three Phase AC < 480V	Direct Current DC, 200-600V
Peak Current	16A	32A	250A	400A
Max Power	0-13.3kW	0-26.6kW	184.4kW	240kW
Safety	power and protective earth equipment	power and protective earth equipment (1000Ω resistor between pilot and earthing to break circuit if current on pilot-earth loop is lost), IEC 61851-1 control pin on EV	same as Mode 2, but control and signal pins for both sides of the cable, socket is dead if no vehicle present, pilot pin in the plug on the charger side controls the circuit break	control and signal pins to ensure operation for fast charging comparable to Mode 3
Coupler	non-dedicated household plug	non-dedicated household plug	IEC 62196-2 Type 1-3, SAE J1772	SAE J1772 Hybrid, IEC 62196-2 Type 2 Hybrid, CHAdeMO
Notes	not allowed by national US codes since earthing is not present in all domestic installations	RCD required for protection, control box must be in the plug or within 0.3 metres of the plug	communication port enables integration into smart grid	communication plug enables integration into smart grid and checks compatibility of connected EV

Charging in Mode 1

The EV is linked to an AC supply network via a regular household plug while charging in Mode 1. The maximum current is limited to 16 amps, and the For a single-phase AC network, the maximum voltage cannot exceed 250V, and for a three-phase AC network, it cannot exceed 480V. Protective earth conductors and an over-current protection mechanism are also necessary for Mode 1. Siemens [23] has proposed a mode 1 charging configuration, which is shown in Figure 2.4. When the electric current between the energized conductor and the return neutral conductor is not balanced, a Ground Fault Interrupter (GFI) is used to interrupt the circuit and a Circuit Breaker (CB) is used to prevent against overcurrent. It is advised to use a surge arrester.

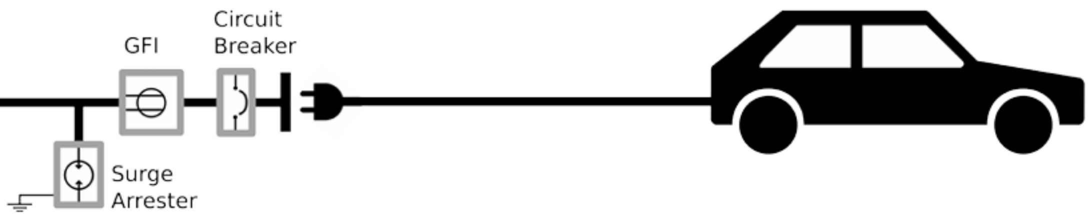


Figure 2.4: Mode 1 EV charging setup recommended by Siemens [23]

For Mode 1 connectors, IEC 61851-1 does not mandate the use of any control pins. In certain nations, including the US, mode 1 charging is prohibited.

Charging in Mode Two

When an EV is connected to an AC supply network with a maximum current of no more than 32A and a maximum voltage of less than, this is known as Mode 2 charging. less than 480V for three-phase networks or less than 250V for single-phase networks. To prevent electric shocks during Mode 2 charging, protective earth, over-current protection, and a residual current protective device are necessary. As shown in Figure 2.5, an inline module in the charging cable integrates a charging control system. Because of this, Mode 2 couplers need a control pin on the vehicle side (which is specified in IEC 61851-2). Nevertheless, since the control system is built within the charging cable, the network side of the cable does not need a control pin.

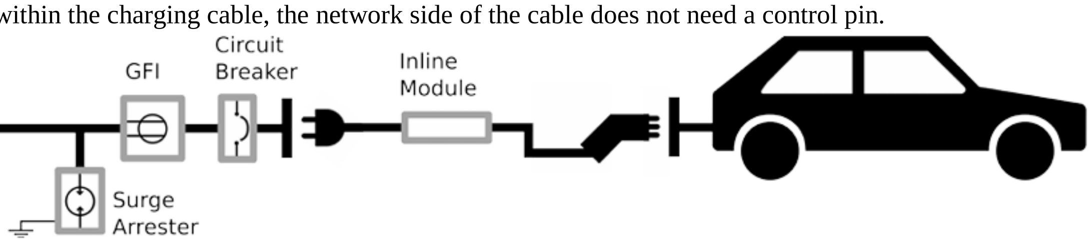


Figure 2.5: Mode 2 EV charging setup recommended by Siemens [23]

Charging in Mode Three

When using Mode 3 charging, the electric vehicle is permanently connected to either a single-phase or three-phase AC network through a charging infrastructure. The levying The Electric Vehicle Supply Equipment (EVSE) control module in the off-board installation and the on-board charger in the EV are in charge of controlling the control pilot function. Siemens has proposed a Mode 3 charging station layout, which is seen in Figure 2.6. A ground fault interrupter inside the charging station and over-current protection are necessary for mode 3 charging. It is advised to use a surge arrester. Multiple control and signal pins must be implemented into the converter in accordance with IEC 61851-2. The circuit breaker that deactivates the charging station is controlled by a pilot pin in the plug on that side.

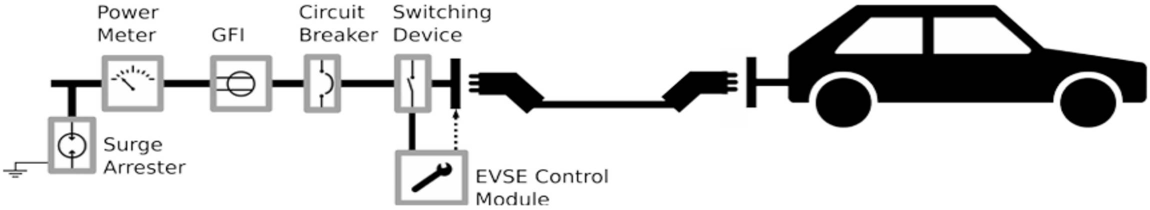


Figure 2.6: Mode 3 EV charging setup recommended by Siemens [23]

Charging in Mode 4

The EV is connected to a single-phase or three-phase AC network via an AC/DC converter while charging in mode 4. To facilitate quick charging, an off-board electric vehicle charger is used. Up to 400A of current can be used for fast charging using mode 4 DC. On the vehicle side (all modes available), the car is attached to an IEC 62196 standardized connector, and on the charging station side, it is connected to an IEC 62196 Mode 3 connector. This configuration is shown in Figure 2.7. Separate over-current protection devices for AC and DC as well as AC/DC-sensitive GFIs are required in mode 4 charging stations. IEC 61851-1 states that the control and signal pins of a Mode 4 connector are comparable to those of a Mode 3 connector.

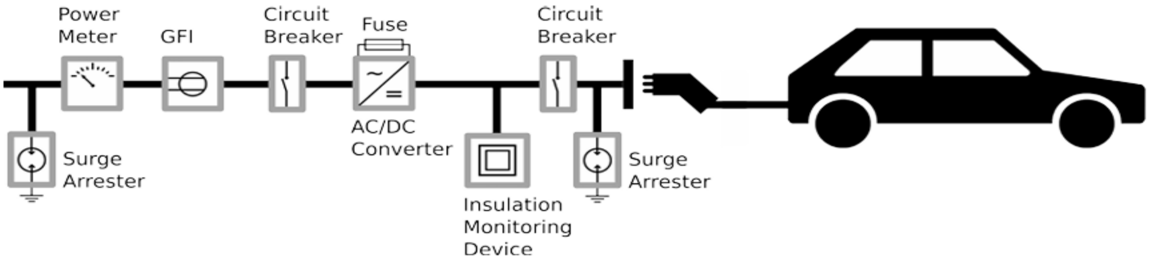
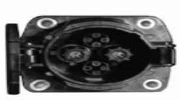


Figure 2.7: Mode 4 EV charging setup recommended by Siemens [23]

2.4 Standards for Connectors

IEC 60309, an international standard for "plugs, socket-outlets and couplers" from the International Electrotechnical Commission (IEC), is referred to as IEC 62196-1. for use in industry. Although EVs still use IEC 60309 plugs, a variety of connecting techniques have been developed especially for EV charging. Three different plug types are described in the IEC 62196-2 standard for connecting to AC supply networks. An overview of these plugs, their use internationally, and international plug standards for DC fast charging are provided in Table 2.3.

Table 2.3: International utilization of charging connectors

	US	EU	Japan	China
Single Phase	 SAE J1772	 SAE J1772/IEC 62196-2 Type 1	 SAE J1772	 IEC 62196 Type 2
Single- or Three Phase		 IEC 62196 Type 2  IEC 62196 Type 3		
DC	 SAE J1772 Hy-brid	 IEC 62196 Type 2 Hybrid	 CHAdeMo	 GB Standard Mode 3

Type 1 of IEC 62196-2

Single phase car couplers use the IEC 62196-2 Type 1 plug. IEC 62196-2 Type 1 connectors are defined under the SAE J1772 2009 standard. Plugs of type 1 have Five pins total (per IEC 61851-2001 / SAE J1772-2001): two for single-phase AC, one for earthing, one for proximity sensing, and one for the control pilot function. Type 1 couplers, IEC 62196, have a 250V at 32A rating (80A in the US).

Type IEC 62196-2

The firm Mennekes created the IEC 62196-2 Type 2 connector by adding pins to IEC 60309 three-phase connectors. It can be applied to supply networks with one or three phases. Its 55mm reduced diameter makes handling it easier.

IEC 62196-2 Single and three phase vehicle couplers with shutters are Type 3 connectors. Two distinct Type 3 connectors were suggested by the EV Plug Alliance. A variation of Type 3a is the Italian Connector for light vehicles (such as e-scooters or e-bikes). The addition of IEC 62196 pins allows for single-phase charging. Two more pins are included in Type 3b for three-phase charging. For three-phase networks, the maximum power is set at 22kW at 32A to enable lower plug and installation costs.

DC Charging Connector

Currently available socket types for DC charging include:

TEPCO in Japan has created the JARI Level-3 DC quick charge connector specifically for CHAdeMO. Up to 62.5kW of high-voltage direct current can be delivered using the DC rapid charging standard CHAdeMO. The JARI's maximum rated current A Level 3 DC connector can handle up to 500V (DC) at 125A. The JEVS (Japan Electric Vehicle Standard) G105-1993 standard contains a description of the JARI standards. Analog control lines and CAN-bus are used to transfer data. This hybrid communication protocol double checks the digital control system, which increases system security. Furthermore, unlike with full digital control, an instantaneous shutdown of the charging process can be carried out in the event of an analog signal loss. There are three steps involved in the CHAdeMO charging sequence [26]: to make sure there are no anomalies, like a ground fault or short circuit. Power supply start-up: the car determines the current level by evaluating the battery's performance together with additional criteria. Through CAN-bus, the computed value is sent to the charger every 0.1 seconds. End of charging: To turn off the charger, the car sends zero current signals across the CAN bus. Following verification, an EV opens the contact and notifies a charger to prevent usage. The charger then verifies that its output current is zero.

Conclusion

The networks supporting EV charging stations are developing quickly. Technical standards have been developed by a number of public organizations, privately held businesses, and technical commissions; they have not yet been streamlined. This study has outlined the main features of several national and international standards for EV charging stations in order to assess the possibilities and constraints of using EV batteries to reduce traffic-related accidents. Other than artificial time limits in communication protocols, no technical limitations have been found. The University of Hawaii is actively looking into the possibilities of EV technology for mitigating TOVs, and future works will reveal the findings.

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